Δελτίο Ελληνικής Γεωλογικής Εταιρείας τομ. XXV/2, 437-452, 1991
Πρακτικά 5ου Επιστημονικού Συνεδρίου, Θεσσαλονίκη, Μάϊος 1990

Bulletin of the Geological Society of Greece vol. XXV/2, 437-452, 1991
Proceedings of the 5th Congress, Thessaloniki, May 1990

THE PETRALONA CRANIUM: C. T. –SCAN FINDINGS

P. Le Floch–Prigent* and A. Moschidou–Polizois

A B S T R A C T

The Petralona cranium was CT-scanned (September 1987) by regular sections every 5 mm with a 7 mm thickness all along the skull in the three orthogonal planes : horizontal with the orbito-meatal lines as the reference (Frankfurt plane), frontal and sagittal. A lot of morphological and architectural results were obtained, mainly the vault's thickness (about 10 mm), the semi-circular shape of the vault on the frontal planes, the shape and relationships of the frontal sinuses and frontal poles of the brain. The morphometry permitted calculation of the intra-cranial capacity by summation of the areas of each series of sections. The real physical value of 1200 cm^3 was obtained with a precision of 0,2 % to 3,3 % depending on the plane (varying with the lack of contourlines).

INTRODUCTION

The Petralona cranium was discovered by villagers in 1960 on the ground of a cave located in Mount Katsika, Chalkidiki peninsula : KOKKOROS and KANELLIS (1960). It is one of the best preserved and largest of the European crania of more than 100 000 years old. The absence of stratigraphy, the large extent of ages of the associated faunas (from 700 000 to approximately 9 000 years old) : TSOUKALA (1990), some variations and doubts on the absolute dates of the calcite deposits (close to 200 000 years old) can not afford more than an estimation between 400 000 and 200 000 years old. The main features assess a probable transition form between a very late *Homo erectus* and a very early *Homo sapiens (neandertalensis)*.

A large number of papers have described this cranium but X-ray radiographs remained the only external physical complementary examination until the eighties and were mainly realized for dental descriptions : the

* Université Paris V, U.F.R. de médecine Paris-Ouest et Biomédicale des Saints Pères, Laboratoire d'Anatomie, 45 rue des Saints Pères, 75270 PARIS CEDEX 06, France.

** Ippokratio Hospital, Department of Radiology of Aristotle University of Thessaloniki, THESSALONIKI, Greece

architectural radiographical findings remained limited ones. To our knowledge, tomograms were not performed on this cranium but a first series of CT-scans was carried out by XIROTIRIS and MELENTIS (1982) but without a complete report of the results published.

We thought that a new CT-scan examination with an orbito-meatal horizontal reference, and series realized also in the frontal and sagittal planes with joined sections, could afford new architectural and detailed morphological features.

MATERIAL AND METHODS

The Petralona cranium is a very well preserved specimen, kept in the Department of Paleontology and Physical Geography in the Aristotle University of Thessaloniki. Some parts are missing : the middle of the right zygomatic arch, the mastoïds, the anterior teeth (incisivors and part of the left canine), and partly the central internal bones of the face which anterior aspect is intact (Fig. 3). The vault is complete (Fig. 1 to 6) and the quite entire endocranium as well. The mandible was never found.

The differences between this cranium and modern man are numerous. The most striking features are the importance of the *torus supra-orbitalis* with a central depression (Fig. 1, 2, 3 and 4), the flattening of the face under the orbital cavities without canine fossa (Fig. 3), the flattening of the temporal squama on its top and its salience in the back, the U form of the alveolar ridge (Fig. 5), the existence of an *occipital torus* (Fig. 5) and the flattening of the base of the occipital bone.

We used a CT-scan (EMI 7070) in the department of Radiology of the Ippokratio hospital (Santa Sofia) in Thessaloniki, in September 1990. The sections were performed in three orthogonal planes all along the cranium contained in a foam form with orientated sides and the axis carved to receive the cranium. We chose the orbito-meatal plane (Frankfurt plane) as the horizontal reference since it was easy to stake out without any damage and could be reproduced on other fossils. The two other planes : sagittal and frontal, were perpendicular to the horizontal one. The joined sections were obtained every 5 mm with a thickness of 7 mm (resulting in a 1 mm overlap on each side). Each section was reproduced on an X-ray film with the best definition possible for bone contours, then this film was photographied on a negatoscope and developped at scale of 1:1. Finally it was reproduced on tracing papers.

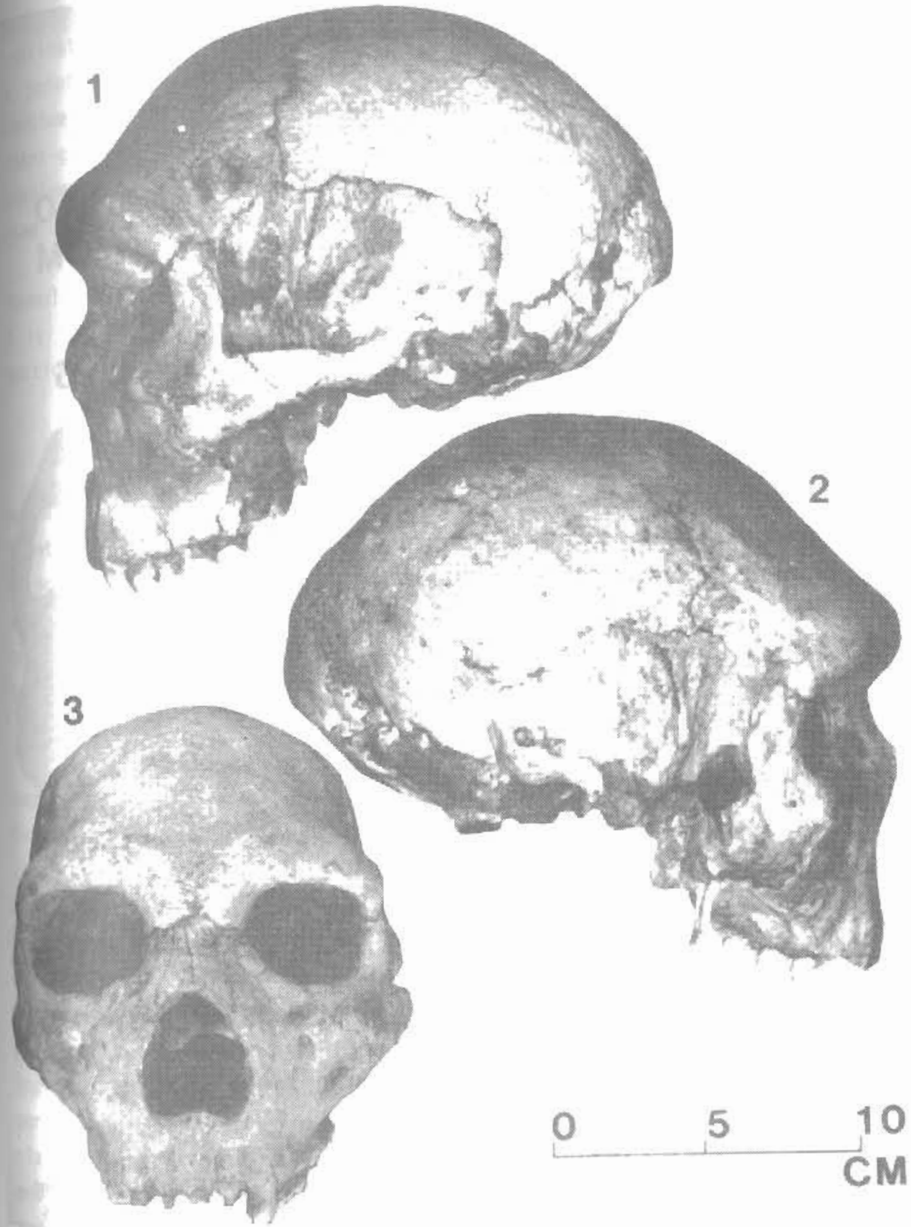
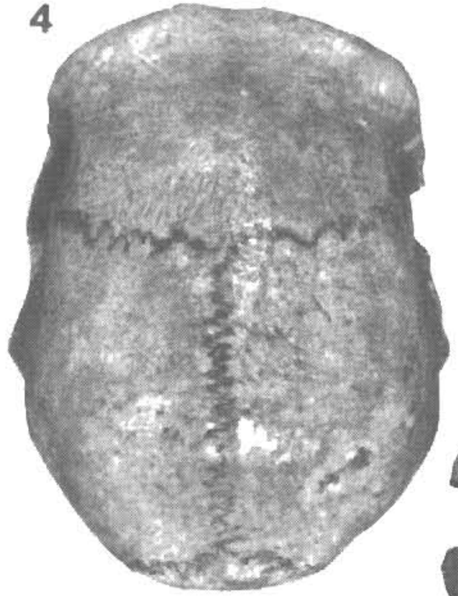
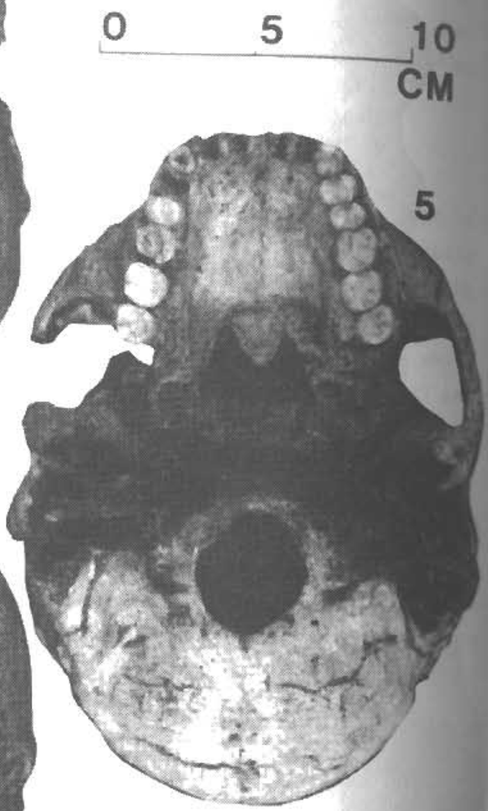


Fig. 1. The Petralona cranium, *norma lateralis sinistra*.
Fig. 2. The Petralona cranium, *norma lateralis dextra*. The middle part of the zygomatic arch is missing.
Fig. 3. The Petralona cranium, *norma anterior*. The *torus supra-orbitalis* is large. The infra-orbital region is flattened.

4





5

6

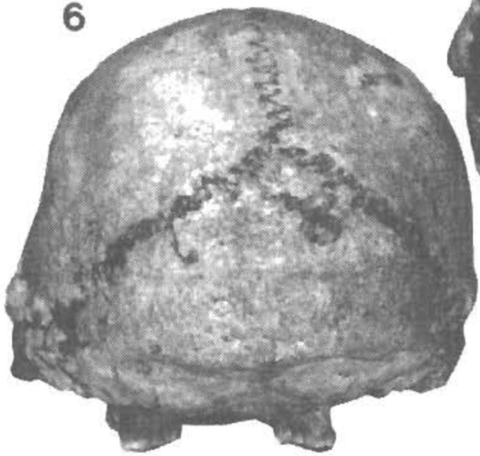


Fig. 4. The Petralona cranium, *norma superior*. The *torus supra-orbitalis* forms an important anterior cap. The anterior part of the temporal fossa is deep.

Fig. 5. The Petralona cranium, *norma inferior*. The median part is still covered by a layer of calcite. The mastoids are cut. The lateral bar of the teeth are straight. A *torus occipitalis* circle the posterior border.

Fig. 6. The Petralona cranium, *norma posterior*. The shape of the vault is semi-circular. The sutura are very denticulate. An epactal bone exists. The salience of the temporal squame is marked.

The point-grids were established : one with a point every one centimeter representing an area of one centimeter square, and another one with a point every five millimeter representing an area of a quarter of one centimeter. The first one was used to measure the surfaces for the intra-cranial cavity and the later for the frontal and maxillary sinuses. A planimetry was performed with an OTT planimeter and the mean of 3 measurements used only for the intra-cranial capacity.

The volumes were integrated from the surface's measurements by the formula, modified from ELIAS and HYDE (1983) $V = t\sum_{n=1}^{i} A_i$ where V is the volume, t is the thickness of each section replaced here by the interval between the sections, A is the area of the structure measured on each section.

RESULTS

1) Number of sections : we obtained for the first examination a total number of one hundred and thirteen (113) sections : thirty eight (38) were frontal, thirty three (33) sagittal, and forty two (42) horizontal. A second CT-scan was performed on September 1988 in the occlusal plane as we judged that the appreciation of the shape of the alveolar bridge was too much biased by the orbito-meatal plane (angulation between these two planes : 19 degrees), eight levels (8) were obtained.

2) Morphology

a) frontal sections (Fig. 7) cut first (front slice) the nasal superior edge and the anterior maxillary ; the nasal fossae and the anterior dental alveolus and frontal sinus were interested on the following sections (backward). The anterior part of the endocranium was present with a transversal pinch of the frontal poles in comparison with modern man (Fig. 7 : F.3). The very large frontal sinuses were demonstrated by this plane of sections as the relationships between the frontal poles and the roof of the orbits. The correspondance between the third posterior part of the orbits and the anterior part of the endocranium is for us a fundamental difference from modern man and indicate a lesser degree of telencephalisation on the evolution scale in the genus *Homo* The *apophysis crista galli* was clearly visible as the cribriform plate of the ethmoid (F.3). On the further sections, the anterior floor of the endocranium was uninterpretable (osseous defects) meanwhile the dental arcade and the osseous palate were clearly designed. The middle floor of the cranial basis was present on seven sections, and the shape of the vault (F.4) was semi-circular with a nearly constant thickness of 10 millimeter (which is more than in modern man). The petrous pyramid was difficult to detail as the

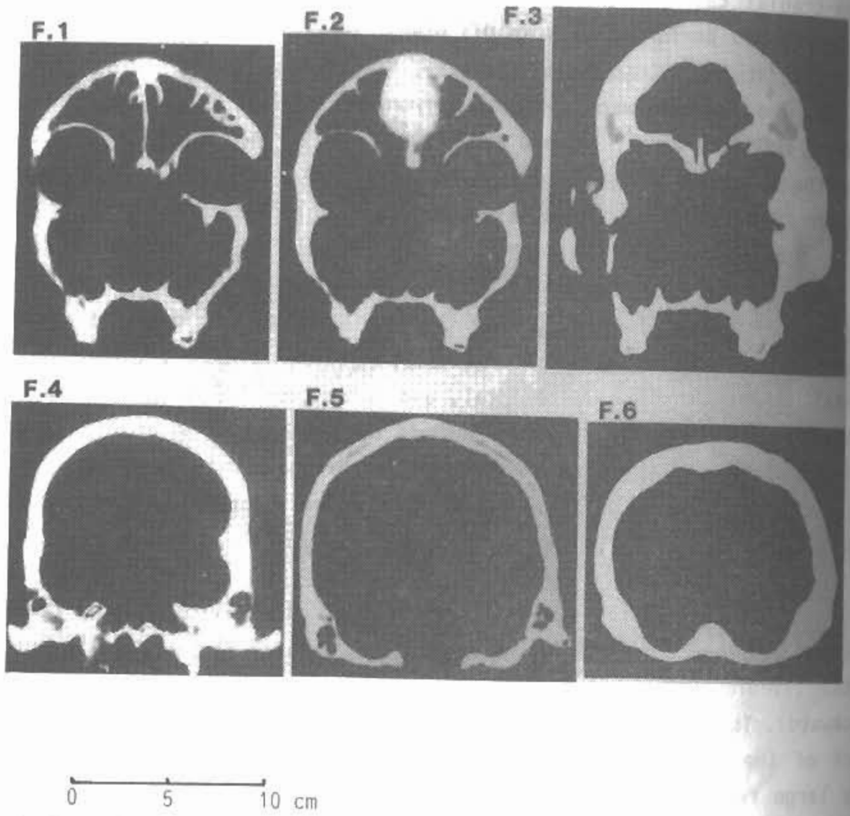


Fig. 7. Frontal cross-sections of the Petralona cranium, selection of the results. F. 1 section through the *torus supra orbitalis* in which some dividing elements are visible, osseous median defects are important in the facial massive. F. 2 section through the osseous frontal pole of the cranium, bordered on each side by the cavity of the *torus supra orbitalis*. F. 3, section through the frontal pole of the intra-cranial cavity; the cribled plane of the ethmoid and the *apophysis crista galli* are well visible. From F.1 to F.3, the osseous palate is transversal and its inferior face quite straight. F.4 section through the petrous bone and the roots of the zygomatic arch, the middle floor of the basis of the skull is well drawn. F.5 section the *foramen magnum*, the cells of the mastoids are large; the shape of the vault is semi-circular. F.6, section behind the *foramen magnum* the basis forms two semi-circular cavities apart an important middle salience. The vault's thickness is about 10 mm on F.4 and F.5; by a tangential effect, it looks larger on F.3 and F.6 .

apparatus was calibrated more to enhance the architecture than to define thin details, the thickness of the sections and their orientation were not appropriate for the temporal bone. The posterior fossa was present on seventeen sections with eight sections passing through the *foramen magnum* (F.5). Behind the condylar masses, the latter was thickened all along its contour. The sagittal salience of the endocranium in its inferior and posterior part (F.6) was wide and high. The posterior pole of the endocranium was far backward in comparison with modern man ; the occipital bumps were pronounced on each side and corresponded to a salience of the *cerebellum* hemispheres in the endocranium. The concentric external saliences of the occipital basis were without internal correspondance. On six successive sections, behind the *foramen magnum* the peripheral external occipital plane was visible with a five millimeter width.

b) horizontal sections (Fig. 8) concerned the vault above the *torus supra-orbitalis* on nine levels ; the *torus* itself on six levels ; the orbits on eight levels ; the nasal fossae on five levels ; the osseous palate on three levels ; the alveolar bridge and the teeth were sectioned again in the occlusal plane on eight levels. The endo-cranial cavity was ovoid with a large posterior extremity on every level (H.1 to H.3). The vault was thick with a good differenciation of the diploë. The *torus supra-orbitalis* formed an additional rectangle (H.2) slightly depressed in front of the *glabella* with a lateral salience in the higher part of the post-orbital fossa. The very large frontal sinuses completely occupied this formation, separated by a sagittal, thin wall ; partial septa came from front to back, eight on each side. The sagittal posterior, internal crest was developped. The internal structure of the petrous bones was difficult to detail (H.4). The semi-circular canals were visible. The transverse width of the retro-orbital fossae was measurable on each level (H.3, H.4). The external wall was thick, and more on the front (H.3, H.4). The internal wall of the orbits was partially present. The contourline of the posterior fossa was flat on the posterior face of the petrous bones (H.4), curved with one or two bumps on the anterior face occipital squame. The maxillary sinuses were limited in the front and laterally (H.5). The development of the pterygoid apophysis on the successive sections was difficult to discern and partially filled with calcite. The alveolar edge of the maxillary sinuses was thick at the level of the osseous palate, it was a U shape underlined by the absence of the incisivors, flattening the frontal aspect. The intra-dental cavities were visible (H.7) on the lateral teeth.

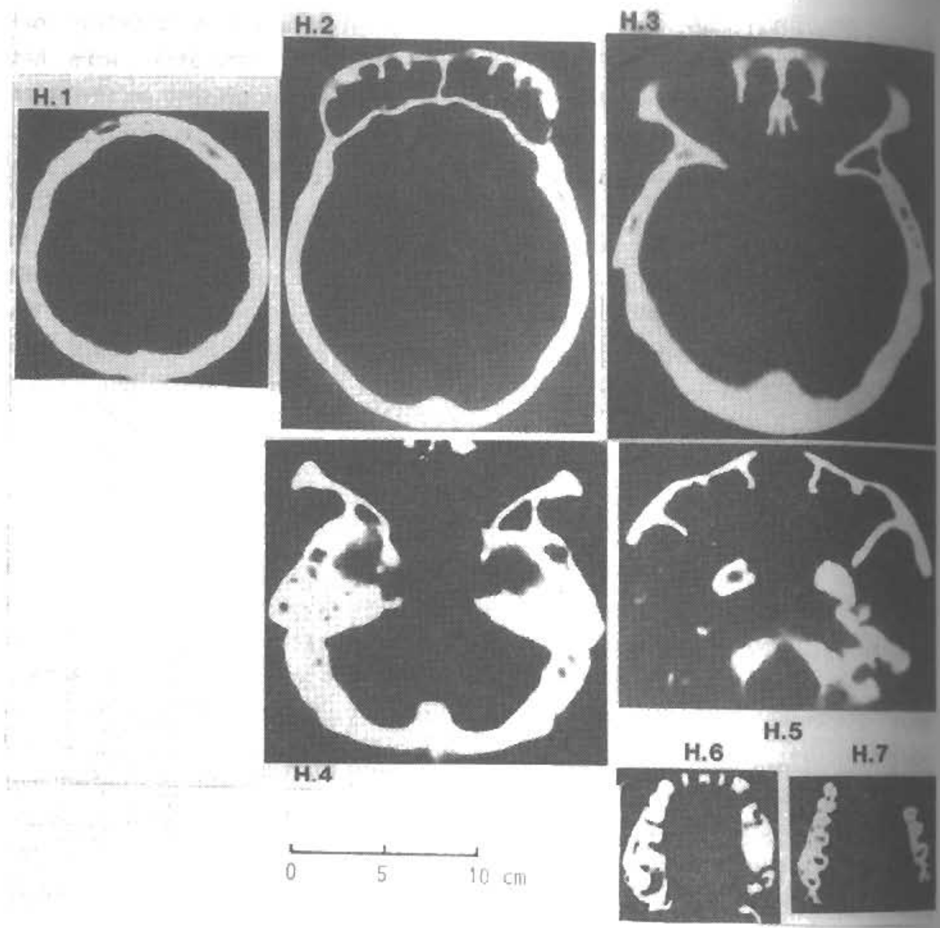


Fig. 8. Horizontal cross-sections. H.1, section above the *torus supra-orbitalis*, the shape is approximately circular with endo-cranial prints, the external and internal tables surround the diploe and are well detailed. H.2, very noticeable section through the *torus supra orbitalis* which two halves are quite rectangular, apart one thin median septum ; subdividing anterior walls are visible. H.3, section through the orbital cavities with a thick lateral wall, notice the large median posterior intra-cranial salience. H.4, section through the lower part of the orbits, the petrous pyramid ; in the posterior fossa, the medial salience is important (as on H.3), the temporal squame protrudes importantly behind the exo-cranial surface. H.5, through the occipital condyles, the anterior face under the orbits is flattened. H.6, through the alveolar maxillary bridge with emptiness of the incisors alveolus. H.7, through the lateral dental bars which are strictly linear, the dental cavity is visible on several molars. The U-shape of the alveolar bridge has to be interpreted on the whole teeth with the vacancy of the incisors which are importantly directed frontwards in *Homo erectus*, so the final form would be more parabolic. The thickness of the vault is about one centimeter on H.1 to H.3, as on the frontal (Fig. 7) and sagittal (Fig. 9) sections. On H.4 and less on H.1, this thickness looks larger by a tangential effect.

c) sagittal sections (Fig. 9) could be classified in four groups : lateral extreme (4 on the left, 3 on the right) which involved only the zygomatic arch and the temporal squame ; lateral of the vault (2 on the left, 3 on the right) which concerned the lateral part of the intra-cranial cavity with the floors of the basis difficult to identify, and the lateral part of the orbit ; median lateral (5 on the left and 4 on the right) where the floors of the basis were distinct and through the middle and medial part of the orbit ; real median (6 on the left as on the right). The mean features were the retro-orbital depression of the temporal fossa (S.2 and S.3), vertical, visible on 4 sections on each side. The orbital walls were vertical (S.2. and S.3.) ; the volume of the frontal sinuses was important (S.3, S.4 and S.5) in the three directions with a thin osseous thickness, except backwards on the level of separation with the endo-cranial cavity. The thickness of the vault was about one centimeter on every point except in front of the *torus supra-orbitalis* and of the middle occipital zone.

3) Morphometry

a) the intra-cranial capacity has a real, physical value of 1200 cc^3. In the frontal plane, the result was 1202,5 cc^3 that is a precision of 0,2% in comparison with the real value (physical measurement by packing), explainable by the ease of completion of the outlines of the endocranium in this series of sections. The result is good in the horizontal plane : 1191,7 cc^3 (by planimetry : 1178 cc^3) with a precision of 0,7%. In the sagittal plane, the value was 1239,5 cc^3 (by planimetry : 1247 cc^3), so the precision was 3,3% ; this was due to the difficulties to complete the internal outlines of the endocranium, in this plane, by bone lacks of the anterior and central parts of the basis.

b) the frontal sinuses had a total value of 60,1 cc^3 in the frontal plane, 61,5 cc^3 in the horizontal plane, and 81 cc^3 in the sagittal plane.

c) the morphometry of the maxillary sinuses gave results difficult to interpret, due partly to the lack of their medial walls.

DISCUSSION

The C.T.-scan results are not able to afford informations about the date of the specimen. C.T.-scan of other types of *Homo* have been performed : WIND (1984) and the intra-cranial capacity of non-hominian fossils was estimated by this method : CONROY and VANNIER (1985) but non on hominoïds. A thickness of one millimeter and a large window with modified scales of values

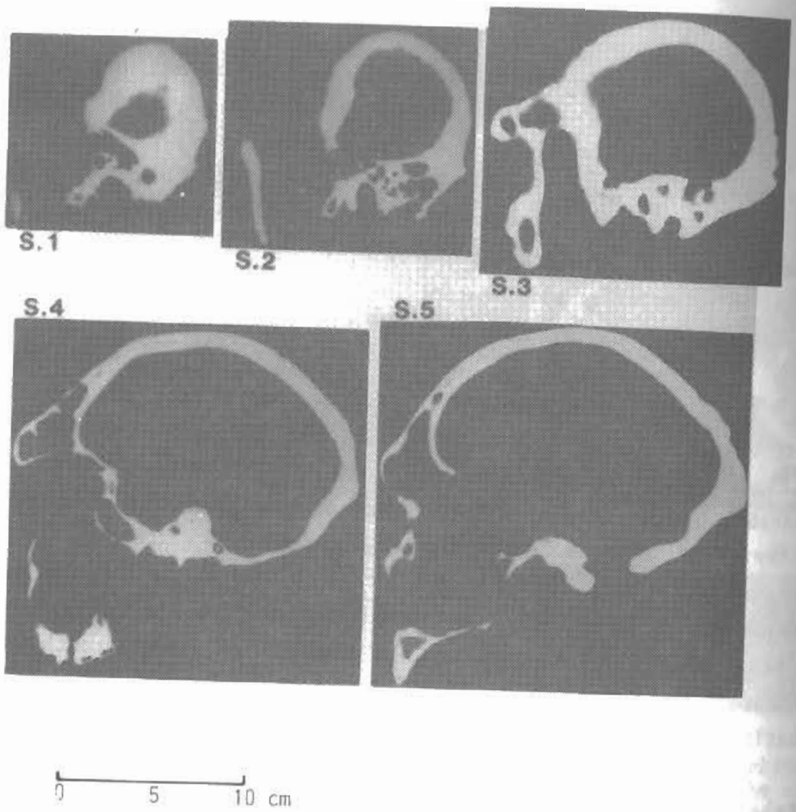


Fig. 9. Sagittal cross-sections. S.1, lateral part of the temporal squame and mastoid. S.2, section through the middle floor of the basis of the skull, the mastoid cells and the lateral orbital edge. S.3, section through the middle floor, the anterior part of the temporal fossa, the lateral part of the frontal and maxillary sinuses. S.4., parasagittal section through the *foramen magnum*, the osseous palate ; the medial defects are important but the frontal sinus is well limited, going up with the external table thinner than the medial one (as on S.4), the thickness of the vault is about one centimeter (as on S.4, from S.1 to S.3. the obliquity of the vault leads to higher artificial values).

allowed to precise the internal structures of fossil hominian temporal bones : WIND and ZONNEVELD (1985, 1988). In Australopithecus, C.T.-scans results were obtained : WIND and ZONNEVELD (1989) on the intra-petrous formations, and on the dentition : CONROY (1988).

The orbito-meatal plane was chosen for pratical reasons as it is always visible by the external examination. It is a reasonable choice for the research purposes, for the explanation of the results to the scientific audience and for the exchanges of data between the different teams involved in the field. The other planes could not be easily chosen as horizontal references. The neuro-ocular one along the optic nerve is not defined on an osseous cranium with empty orbits ; the vestibular plane would be difficult as the sample could not be damaged for the horizontal semi-circular canal ; the bi-commissural plane would be easy to plot by nuclear magnetic resonance more than by C.T.-scan but only on the brain, which is absent on the fossils. The difficulties in performing the C.T.-scan examination on often fragile samples, characterized by their uniqueness or rarity, the necessity to transport it to a Radiological department with several manipulations on the table of the apparatus impose that this examination remains unique or with only a limited number of attempts except where there are drastic modifications in the performances of the technique. Thus the results have to be the most widely spread in the scientific world to justify the (very limited) risks and (relatively) high cost of the C.T.-scan. The interpretation of the C.T.-scan has to be careful as constant reference to the original bones is necessary. A long stay with the original fossil is essential for study of the sections obtained by C.T.-scan.

The C.T.-scan morphometry is possible if the cross-sections are joined in orientated planes, with known thickness of the slices and a constant interval between them. The estimation of the intra-cranial capacity is accurate if the technical conditions are perfect and if the endo-cranium is intact. Filled endo-cranium cavities would not be a real obstacle to morphometry as even stones can be penetrated through by the X-rays of the C.T.-scan with good morphological results : ZONNEVELD (1989). The multiplication of the planes of sections affords supplementary validity in case of missing bones as in this case, but theoretically one series is sufficient to measure the intra-cranial capacity or the sinus' volume.

The C.T.-scan findings of the Petralona cranium LE FLOCH-PRIGENT (1989, 1989, 1989) do not afford elements to the age of the fossil as it is only a physical examination, however by addition of numerous characters of description and enhancement of many others, they confirm the usual place devoted to this cranium between *Homo erectus* and *Homo sapiens* and nearer of the later in the time : STRINGER (1974), STRINGER, HOWELL and MELENTIS (1979), STRINGER (1983) ; the morphological findings are in accordance with the absolute datation of the calcite over the cranium : HENNIG, HERR, WEBER and XIROTIRIS (1981).

CONCLUSIONS

The precision of the morphological and morphometrical results obtained by the C.T.-scan of the Petralona cranium is a good reason to hope that the seriated sections in referenced and orthogonal planes will become a standard in paleo-anthropology for the complementary morphological description and the estimation of brain volume, even before the complete clearance of the vault and of the intra-ranial cavity of newly discovered specimens. One could notice that several famous fossil specimens are still incompletely disengaged from their matrix, several decades after their discovery. The results will be best as osseous structures will be the most complete and a quite absolute precision will be obtained on intact samples. The calculation of the volumes of the sinuses by C.T.-scan morphometry is without comparison with other methods. C.T.-scanning of the fossils can also be a help to their disengagement by the nehancement brought to the separation between the fossil bone and the stone matrix.

ACKNOWLEDGMENTS

We are debtful to Prof. J. MELENTIS, Prof. KARAMANLIDIS and Prof. EFREMIDIS for the work on the cranium and its C.T.-scan. The radiological examination was help by A. HARDABILA and colleagues. The constant assistance of Dr. E. TSOUKALA was of an insetimable value. Prof. C.A. MANDARIM DE LACERDA taught us the morphometrical methods during his three years stay in Paris. M. SOUDIERE developed the photographs. C. ROSSELIN and J. Mac INTOSH kindly revised the english.

ADDENDUM

An attempt of reconstitution of the head and neck was done by the first author from the lateral and front view of the cranium (photographs and traces) , added to a mandibule from the Arago site in France related to the same age in the human evolution. We realized two acrylic paints at scale 1/1 : profile and front (Fig. 10 and 11), and one sculpture carved in a calcareous stone also at scale 1/1 (approximately ; Fig. 12).

REFERENCES

CONROY, G.C. (1988). Alleged synapomorphy of the M1/I1 eruption pattern in robust australopithecines and *homo* : evidence from high-resolution computed tomography. - *Amer. J. Phys. Anthrop.*, 63, 487-492.

CONROY,, G.C. & VANNIER, M.W. (1985). Endocranial volume determination of matrix-using high-resolution computed tomography. *In P.V. TOBIAS (ed.) "Hominid evolution : Past, Present and Future"*, 419-426, New York, Liss.

ELIAS, H. & HYDE, D.M. (1983). A guide to practical stereology. Bale, Karger.

HENNIG, G.J., HERR, W., WEBER, E & XIROTIRIS, N.I. (1981). ESR-dating of the fossil hominid cranium from Petralona cave, Greece. - *Nature*, 292, 533-536.

KOKKOROS, P. & KANELLIS, A. (1960). Découverte d'un crâne d'homme paléolithique dans la péninsule Chalcidique. - *Anthropologie*, 64, 438-444.

LE FLOCH-PRIGENT P. (1989). C.T.-scan morphometry applied to intra-cranial capacity and para-nasal sinuses of a fossil cranium : the Petralona man (Northern Greece). *Rev. bras. Cien. morfol.*, 6, 105-109.

LE FLOCH-PRIGENT P. (1989). Scannographie du crâne de Pétralona : coupes systématiques dans les trois plans ; 1ère partie : résultats morphologiques. - - *Comptes rendus de l'Académie des Sciences*, II, 309, 1855-1862.

LE FLOCH-PRIGENT P. (1989). Scannographie du crâne de Pétralona , 2ème partie : morphométrie et discussion. - *Comptes rendus de l'Académie des Sciences*, II, 309, 1997-2003.

STRINGER, C.B. (1974). A multivariate study of the Petralona skull. *J. Hum. Evol.*, 12, 731-742.

STRINGER, C.B., HOWELL,F.C. & MELENTIS J.K. (1979). The significance of the fossil hominid skull from Petralona, Greece. - *J. Arch. Sc.* , 6, 235-253.

STRINGER, C.B. (1983). Some further notes on the morphology and dating of the Petralona hominid. - *J. Hum. Evol.*, 12, 731-742.

TSOUKALA, E. (1990). Contribution to the study of the Pleistocene fauna of large mammals (Carnivora, Perissodactyla, Artiodactyla) from Petralona cave, Chalkidiki (N. Greece). Doctorate thesis, *Sci Ann. School Geol., Aristotle University of Thessaloniki*, 1(8), 1-360, I-LVII pl., Thessaloniki.

WIND, J. (1984). Computerized X-ray tomography of fossil hominid skulls. -*Amer. J. Phys. Anthrop.*, 63, 265-282.

WIND, J. & ZONNEVELD, F.W. (1985). Radiology of fossil hominid skulls. *In P.V. Tobias (ed.) "Hominid evolution : Past, Present and Future"*, 437-442, New York, Liss.

WIND, J. & ZONNEVELD, F.W. (1989). Computed tomography of an *Australopithecus* skull (Mrs Ples) : A new technique. - *Naturwissenschaften*, 76, 325-327.

XIROTIRIS, NI. & MELENTIS J. (1982). New studies on the Petralona skull. *In V.V. NOVOTNY (ed.) : IInd Anthropological congress of Alès Hrdlicka*, 437-442.

ZONNEVELD, F.W. & WIND, J. (1985). High-resolution computed tomography of fossil hominid skulls : a new method and some results. *In P.V. TOBIAS (ed.) "Hominid evolution : Past, Present and Future"*, 427-436, New York, Liss.

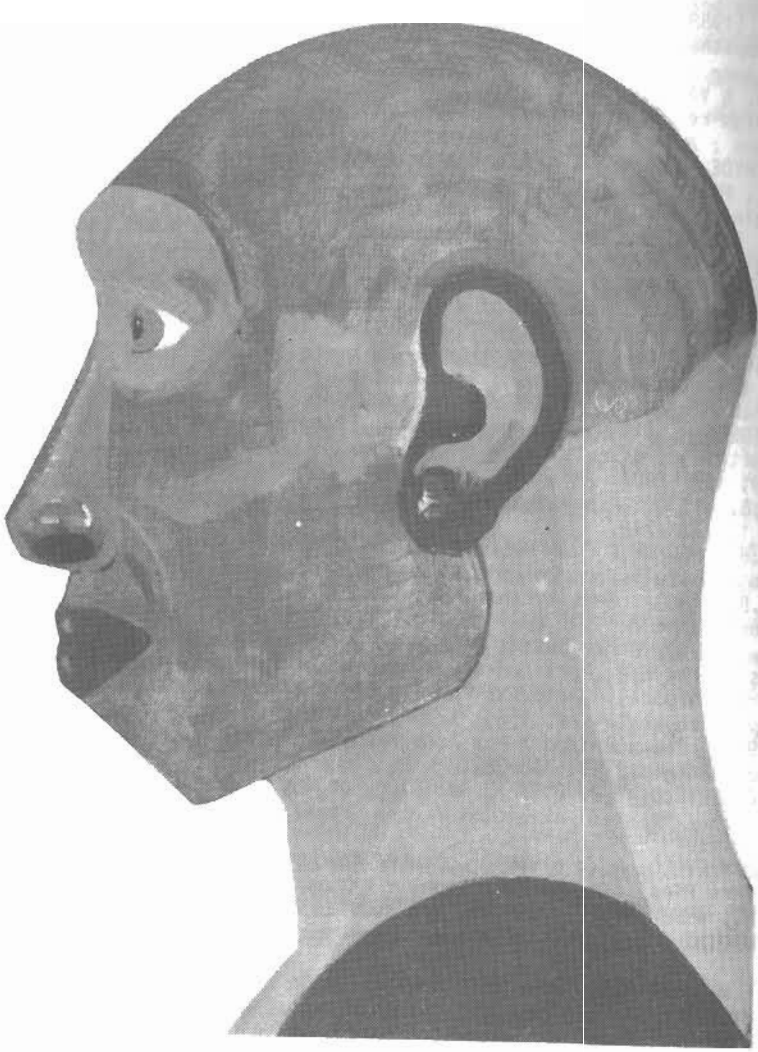


Fig. 10. Reconstitution of the head and neck of the Petralona man : profile. Acrylic painting by coverage of the trace of the cranium and mandible from Arago photographed at scale 1/1. The only unknown features are the colors, the thickness of the lips, the shape of the external ear here inspired from modern man and adaptated by the reasoning of the, extremes between great apes (chimpanze and gorilla) and the living man. The shape of the nose and the place of the eye, nose, lip and external ear are the real one as they are conditioned by the osseous features and places. The rate of reduction from the original painting is 61%.

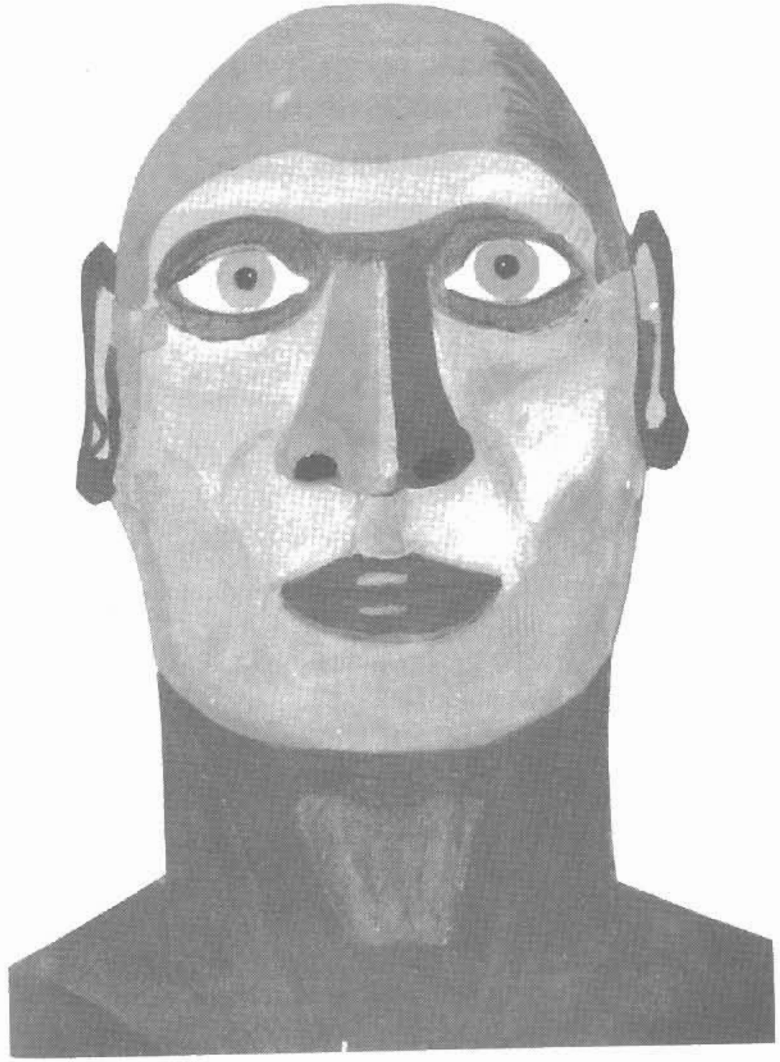


Fig. 11. Reconstitution of the head and neck of the Petralona man : front view Acrylic painting by coverage of the trace of the cranium and mandible from Arago photographed at scale 1/1. Colors of the skin and eyes are completely unknown. The shape of the nose and its place are closely determined by their place and features on the osseous cranium and fac[illegible] The rate of reduction from the original painting is 61%.

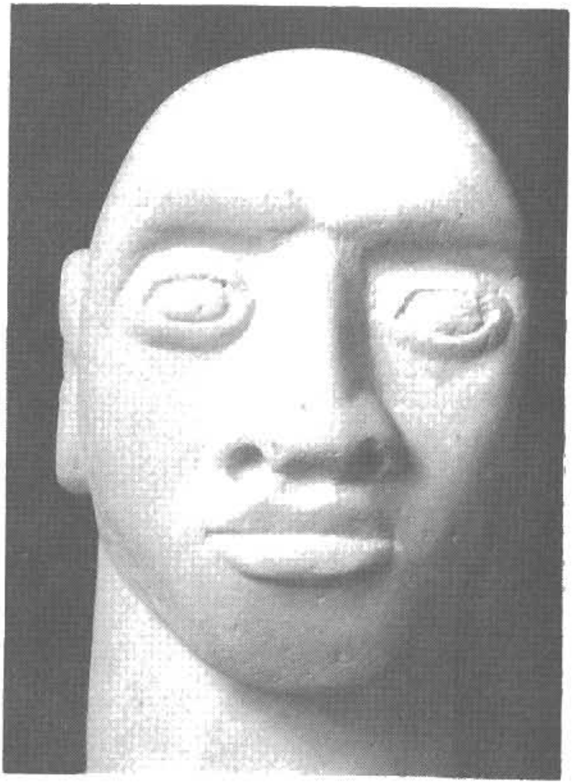


Fig. 12. Reconstitution of the head and neck of the Petralona man : front view of a sculpture carved at scale 1/1 in a calcareous block. The photographs outlines (front and profile) were traced on the sides of the block and the sculpture realized with constant reference to the osseou cranium (plaster cast) and a mandible from the Arago, and to the paintings (Fig. 10 and 11). The carving was done by the first author in the workshop of a professional sculptor : Robert JUVIN, in Paris who constantly gave his advices and help for difficult parts : nose, eyes, ears, mouth. The rate of reduction of this view is 42% from the original.

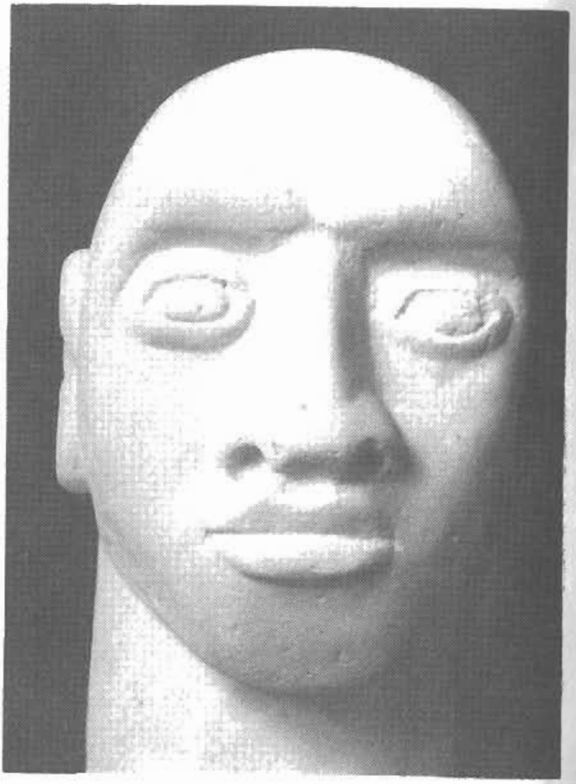


Fig. 12. Reconstitution of the head and neck of the Petralona man : front view of a sculpture carved at scale 1/1 in a calcareous block. The photographs outlines (front and profile) were traced on the sides of the block and the sculpture realized with constant reference to the osseous cranium (plaster cast) and a mandible from the Arago, and to the paintings (Fig. 10 and 11). The carving was done by the first author in the workshop of a professional sculptor : Robert JUVIN, in Paris who constantly gave his advices and help for difficult parts : nose, eyes, ears, mouth. The rate of reduction of this view is 42% from the original.